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FIELD	GROUP	SUB-GROUP	high T_c superconductors, Heavy Fermion superconductors, Surface Acoustic Waves, reentrant superconductors, 2-D electron gas, granular superconducting film.

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

High T_c superconducting controlling elements for frequency tunable surface acoustic wave SAW filters and dispersion lines in the 0.5 to 4 GHz range have been proposed and designed. Ultrasonic attenuation and velocity measurements in sinter forged $YBa_2Cu_3O_7$ indicate that the sound waves are interacting with excitations which are confined to the CuO planes. Proximity SAW coupling to a two-dimensional electron gas 2 DEG has placed limits on the localization lengths of the 2 DEG. A new phase transition has been ultrasonically discovered in the mixed state of the heavy Fermion superconductor UPt_3.

An anomalous increase in attenuation in the superconducting state of the reentrant superconductor system $Er_{1-x}Ho_xRh_4B_4$ implies a novel interaction mechanism in this system.

SAW measurements on granular superconducting films demonstrate that SAW measure the sheet resistivity of these films on a length scale comparable to the SAW wavelength.

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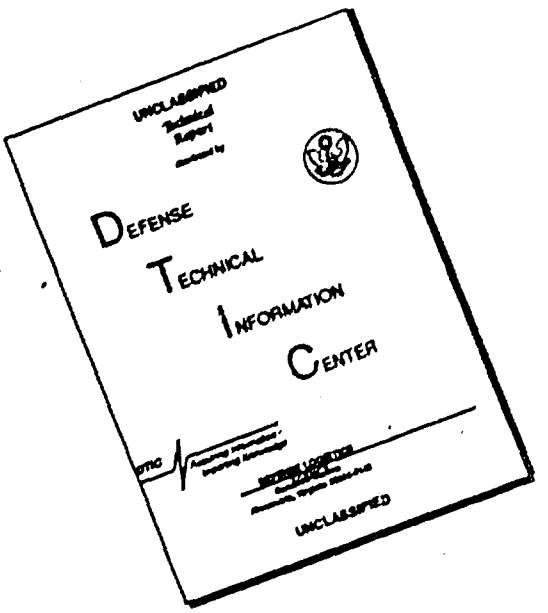

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RESEARCH OBJECTIVES AND APPROACHES

The objective of this investigation was to characterize high T_c superconducting films and other unconventional superconductors with surface acoustic waves (SAW) and bulk waves. By measuring the acoustoelectric coupling of the SAW to the sheet resistivity of high T_c films with mosaic or granular structures both in the normal and superconducting states it is possible to determine the distribution of the intergranular resistances. Bulk wave measurements on high T_c superconductors and other unconventional superconductors may uncover some of the mechanisms that produce superconductivity in these systems; and may even discover if there are some common features in the response to ultrasonic waves which may be associated with the unconventional nature of the superconductivity in these systems.

ACCOMPLISHMENTS

I. High T_c Superconductors

(A) Surface Acoustic Wave Measurements

The attenuation of 1 GHz electromagnetic waves emitted from a pair of interdigital electrodes, travelling parallel to a film of $YBa_2Cu_3O_7$ a few μm thick deposited on a MgO substrate and then received by another pair of interdigital electrodes has been measured. We find an increase in attenuation immediately below T_c followed by an exponential decrease. We have developed a theoretical model which qualitatively appears to explain our data on this film if we assume that the electromagnetic absorption is determined by the real part of the conductivity in the superconducting state which has the BCS coherence factor which is appropriate for nuclear spin relaxation and electromagnetic absorption. We find that it is possible to fit our data with a complex superconducting energy gap, produced by thermal phonon broadening of the quasiparticle states. We obtain the best fit for a zero temperature value of the energy gap equal to $\Delta = kT_c$. (Publication #1)

We have proposed that frequency tunable SAW filters and dispersion lines may be made with high T_c films with large sheet resistivities. We have demonstrated that the attenuation of 700 MHz surface acoustic waves can be changed by as much as 30 dB/cm when a superconducting film is placed between the transmitting and receiving interdigital electrodes of a piezoelectric SAW delay line and the film is heated above its superconducting transition temperature. The SAW couple to the sheet resistivity $R_\square$ of the metallic film through the acousto-electric effect. The normal $R_\square(N)$ of the NbN film used in this experiment was about 29 kΩ/□. If it is possible to produce such large $R_\square(N)$ high T_c superconducting films, with small critical currents and sharp transitions, then these films could be used as switches in SAW delay lines. They could also be used to produce variable bandwidth SAW filters and dispersion lines made of reflective array compressors or slanted SAW transducer devices. The superconducting films would be placed between the reflecting chevrons or slanted transducers and their sheet resistance could be restored by heating with a laser beam or by passing a current through a properly designed film array. (Publication #2)

(B) Bulk Wave Measurements

Both ultrasonic attenuation and velocity measurements have been done on sinter forged samples of superconducting $YBa_2Cu_3O_7$. In these samples 80% of the crystallites have their c-axis aligned within 20° of the forging axis. The attenuation data for longitudinal waves display three broad maxima at 250K, 160K and 70K when the sound waves propagate perpendicular to the forging axis or parallel to the CuO planes. Only one broad maximum is observed for both longitudinal and shear waves at 160K for waves propagating parallel to the forging axis or parallel to the c-axis. For higher frequencies the position of this peak moves to higher temperatures. The anisotropies in the attenuation maxima may indicate that the sound waves are interacting with excitations which may be confined to the CuO planes. The

velocity showed evident anomalies, hysterises and anisotropies. (Publication #3)

Attenuation measurements on a superconducting sample of sintered $YBa_2Cu_3O_7$ exhibited a broad maximum around T_c which shifted to higher temperatures as the frequency was increased from 10 MHz to 32 MHz. This behavior is indicative of a relaxation mechanism with a relaxation time having an estimated activation energy of about 400 K, which is close to the Debye temperature of $YBa_2Cu_3O_7$ as determined from specific heat measurements. (Publication #4)

When the initial activity on high T_c started we also measured the resistivity, a.c. susceptibility and ultrasonic attenuation on high T_c superconducting samples grown at UWM and pressed pellet samples obtained from various other labs (Houston, Ames, NRL). These measurements resulted in publications 5, 6, 7, and 8.

In a single phase $YBa_2Cu_3O_7$ sintered sample obtained from NRL, two maxima in longitudinal wave attenuation were observed, one at 250 K and the other slightly below the superconducting transition temperature, publication No. 9. It is possible that both of these maximum may be produced by relaxation processes involving soft plasmons.

II. Quantum Hall Effect

In publications No. 10 and 11, we report the first results on proximity coupling of surface acoustic waves to a two dimensional electron gas in a GaA_s-$Al_xGa_{1-x}As$ heterojunction. Oscillations in the attenuation of the surface acoustic waves corresponding to the Shubnikov-de Haas oscillations in the conductivity, σ_{xx}, were observed as a function of applied magnetic field. In publication No. 12 we report the results of a study of the frequency and power dependence of the SAW attenuation produced by the two dimensional electron gas on the interface of a GaAs-$Al_xGa_{1-x}As$

heterojunction. The minimum in attenuation, seen at integer numbers of filled Landau Levels increased with increasing power of the surface wave, particularly for the higher number of filled Landau levels. Lower powers were required to produce this increase at higher frequencies. These effects are interpreted as due to heating, resulting from absorption of energy from the surface wave by the electronic states with localization lengths of the order of the acoustic wavelength.

The above measurements prove that proximity coupling of the acoustoelectric effect can be achieved at low temperatures, and that the coupling is dependent on the ratio of a localization length to the acoustic wavelength. These concepts would be important in the design of superconducting frequency tunable filters and dispersion lines.

III. Heavy Fermion Superconductors (UPt_3 and URu_2Si_2)

Samples of these materials were obtained from Argonne National Laboratory (D. Hinks). Ultrasonic attenuation measurements confirm that these are unconventional superconductors (i.e. non-singlet pairing; the pairing is in a higher angular momentum state). A thorough study in a magnetic field was done on the UPt_3 sample. A new feature (a peak in the attenuation) was discovered (independently and almost simultaneously with Muller, et al in Germany). This new feature may be a phase transition, between two different vortex structures. These data have been reported in publications 13, 14, 15, 16, 17, 18 and 7.

The measurements on the second heavy-fermion system URu_2Si_2, reported in Publication No. 7, were performed in a ^3He cryostat. A maximum in attenuation was found below the superconducting transition temperature T_c of URu_2Si_2. A magnetic field decreased this maximum.

IV. Ferromagnetic Superconductors

Bulk ultrasonic measurements in the series of ferromagnetic superconductors $Er_{1-x}Ho_xRh_4B_4$ with x = 1, 0.912, 0.813, and 0.6 (received from Dr. Brian Maple, UCSD) appear to indicate that spin phonon interaction is suppressed by crystalline electric fields but superconductivity screens these fields permitting the interaction to appear. This may be the reason for the increase in attenuation that we have observed in the superconducting state of these ternary compounds. These results are reported in publication No. 19, 20, and 21.

Measurements on a sample with x = 0.295, in addition to the ones above, exhibit a maximum in attenuation centered around 10 K which moves down in temperature as x is decreased. This maximum may be associated with a relaxation process involving a ground state of the Ho ions. The x = 0.295 sample also exhibits another broad maximum around 4 K which is similar to the one reported around 5 K on a polycrystalline sample with x = 0.

V. SAW Measurements on Superconducting Films

Both the dc electrical resistivity and the surface acoustic wave (SAW) attenuation coefficient were measured in the superconducting state of a granular lead film as a function of an applied magnetic field normal to the film plane at several constant temperatures. Measurements were performed when the film had a sheet resistivity of 2000 Ω/sq and 3000 Ω/sq. These different sheet resistivities were obtained by oxidizing the film in place. The initial sheet resistivity of the film was 1000 Ω/sq. Both sets of measurements appear to indicate upper critical fields for this film of 60 K Gauss at 4.2 K. Measurements on lead films are covered in publications No. 22, 23, and 24. Similar measurements on In/InOx films are shown in Publication No. 25.

We have evolved a theoretical model that takes into account renormalization to explain the experimental discrepancy in the superconducting state between the SAW attenuation in a NbN film and its sheet resistivity. The film has a BCS transition temperature of about 10 K, and a Kosterlitz-Thouless transition temperature of 5 K, and a normal state sheet resistivity of 30 KΩ/sq. An exact solution has been found for the renormalized dielectric function of a two dimensional conductor which has Kosterlitz-Thouless flux line dipoles. These results are presented in publications 26 and 27.

Measurements of the attenuation produced by a granular Al film in close proximity above the path traversed by a surface acoustic wave have been made at several frequencies between 19 MHz and 281 MHz. The sheet resistivity of the film is about 1000 Ω/sq. The coupling between the SAW and the film is through the acoustoelectric effect, namely the piezoelectric fields accompanying the SAW induce currents in the film which absorb energy thereby attenuating the SAW. These results are presented in publication No 28.

In publications 29 and 30, a theoretical model is developed for determining the contribution of electron phonon interaction to the attenuation of SAW in the limit that the electron mean free path is larger than the wavelength of the SAW. Previous models only addressed the limit where the mean free path was smaller than the wavelength.

In publication No. 31 a review of SAW measurements on superconducting films is presented.

VI. Dilution Refrigerator

The Oxford dilution refrigerator was installed and tested. The base temperature reached was 5 mk under no load. However, no experiments are possible in this mode. After testing, 8 Co axial and 54 electrical leads specially designed for low temperature applications were added.

The system was then modified to do ultrasonic acoustic measurements in the top-loading mode. This permits a rapid change of samples, without having to open up the system. This resulted in publication No. 32. All design, machining and installation were done at UWM. This is the first top-loading dilution refrigerator system allowing measurements, acoustics or nmr, with a high frequency co-axial contact.

PUBLICATIONS

Thirty two papers have been published.

1. "RF Electromagnetic Investigation of an $YBa_2Cu_3O_7$ Thin Film by Proximity Coupling," H-P. Baum, A. Schenstrom, Y. Zheng, B. K. Sarma, M. Levy, J. H. Kang, and R. T. Kampwirth, IEEE Transactions on Magnetics 25, 987-989 (1989).

2. "Superconducting Frequency Tunable SAW Filter and Dispersion Line," H.-P. Baum, B. K. Sarma and M. Levy, 1989 IEEE MTT-S International Microwave Symposium Digest, p. 639 (IEEE 89 CH 2725-), Publ. Kenneth J. Russel, IEEE, New York, 1989).

3. "Ultrasonic Measurements in Sinter-forged High Tc Superconductor $YBa_2Cu_3O_{7-\delta}$," M-F. Xu, A. Schenstrom, Y. Hong, D. Bein, B. K. Sarma, M. Levy, Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeier and J. B. Ketterson, IEEE Transactions on Magnetics 25, 2414-2417 (1989).

4. "Relaxation Behavior of Ultrasonic Attenuation in $YBa_2Cu_3O_7$," K. J. Sun, W. P. Winfree, M-F. Xu, B. K. Sarma, M. Levy, R. Caton and R. Selim, Applied Superconductivity Conference, IEEE Transactions on Magnetics 25, 2410-2413 (1989).

5. "Ultrasonic Attenuation Measurements on $LuBa_2Cu_3O_7$ and $HoBa_2Cu_3O_7$," K. J. Sun, M. Levy, B. K. Sarma, H. C. Ku, H. D. Yang, R. N. Shelton, R. W. McCallum and P. Klavins, Mod. Phys. Lett. B2, 1279-83 (1988).

6. "Utrasonic Measurements on Polycrystalline $YBa_2Cu_3O_{6+\delta}$," K. J. Sun, M. Levy, B. K. Sarma, P. H. Hor, R. L. Meng, Y. Q. Wang and C. W. Chu, Physics Letters A131, 541 (1988).

7. "Ultrasonic Attenuation Measurements in High T_c Superconductors and Heavy-Fermion Superconductors," M. Levy, M.-F. Xu, H.-P. Baum, A. Schenstrom, Y. J. Qian, K. J. Sun and B. K. Sarma, IEEE 1987 Ultrasonics Symposium Proceedings, 1151 (87 CH 2492-7, Ed. B. R. McAvoy, IEEE, New York, 1987).

8. "Single Target Sputter Deposition, Post Processing and Electron Spectroscopy of Perovskite Superconductor Thin Film," Z. Han, L. Bourget, H. Li, M. Ulla, W. S. Millman, H.-P. Baum, M.-F. Xu, B. K. Sarma, M. Levy and B. P. Tonner, Thin Film Procesing and Characterization of High-Temperature Superconductors, ed. James M. E. Harper, Richard J. Colton and Leonard C. Feldman, American Institute of Physics, 1987.

9. "Ultrasonic Attenuation Measurements in Single Phased $YBa_2Cu_3O_7$," M.-F. Xu, H.-P. Baum, A. Schenstrom, B. K. Sarma, M. Levy, K. J. Sun, L. E. Toth, S. A. Wolf and D. U. Gubser, Physical Review B37, 3675 (1988).

10. "Oscillations in the Acousto-Electric Proximity Coupling to a 2D Electron Gas," A. Schenstrom, Y. J. Qian, M.-F. Xu, H.-P. Baum, M. Levy and B. K. Sarma, Solid State Commun. 65, 739 (1988).

11. "Oscillations in the Attenuation of Surface Acoustic Waves Due to Proximity Coupling to a 2D Electron Gas," A. Schenstrom, M.-F. Xu, H.-P. Baum, B. K. Sarma, M. Levy and Y. J. Qian, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto. 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 759.

12. "Frequency Dependent Breakdown of the Dissipationless State in the Quantum Hall Effect," A. Schenstrom, B. K. Sarma, M. Levy and H. Morkoc, Solid State Communications 68, 357 (1988).

13. "Possible Phase Transition in UPt_3 in a Magnetic Field, M.-F. Xu, Y. J. Qian, A. Schenstrom," H.-P. Baum, J. B. Ketterson, D. Hinks, M. Levy and Bimal K. Sarma, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 1259.

14. "Oscillations in Ultrasonic Attenuation: Real or Spurious?" Y. J. Qian, A. Schenstrom, M.-F. Xu, H.-P. Baum, Bimal K. Sarma, M. Levy and J. B. Ketterson, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 1733.

15. "Ultrasonic Investigation of Novel Superconducting Systems," M. Levy, A. Schenstrom, K. J. Sun and B. K. Sarma, Novel Superconductivity 243 (Eds. Stuart A. Wolf and Viadimir Z. Kresin, Plenum Press, New York 1987).

16. "Field Dependent Behavior of Longitudinal Ultrasonic Attenuation in UPt_3," M.-F. Xu, A. Schenstrom, H.-P. Baum, Y. J. Qian, J. B. Ketterson, D. J. Hinks, M. Levy and B. K. Sarma, Proceedings of Conference on Magnetism and Magnetic Materials, Chicago, Nov. 9-12, (1987), J. of Appl. Physics 63, 3420 (1988).

17. "Shift in Maximum of Sound Attenuation with Magnetic Field in UPt_3," H.-P. Baum, M.-F. Xu, Y. J. Qian, A. Schenstrom, J. B. Ketterson, D. H. Hinks, M. Levy and B. K. Sarma, Proceedings of Conference on Magnetism and Magnetic Materials, Chicago, Nov. 9-12, (1987), J. of Appl. Physics 63, 3686 (1988).

18. "Longitudinal Sound Measurements on UPt_3 in a Magnetic Field," Y. J. Qian, M.-F. Xu, A. Schenstrom, H.-P. Baum, J. B. Ketterson, D. Hinks, M. Levy and B. K. Sarma, Solid State Commun. 63, 599 (1987).

19. "Ultrasonic Attenuation Measurements of Er_{1-x} $Ho_xRh_4B_4$," K. J. Sun, M. Levy, M. B. Maple and M. S. Torikachvili, Proceedings on Materials and Mechanisms of Superconductivity, (eds. K. A. Gschneider, Jr. and E. L. Wolf, North Holland Publishing Co. 1985) Physica 135B, 323 (1985).

20. "Ultrasonic Attenuation Measurement of the Re-entrant Superconductor $Er_{0.187}Ho_{0.813}Rh_4B_4$," Keun J. Sun, Moises Levy, M. B. Maple and M. S. Torikachvilli, IEEE 1985 Ultrasonics Symposium Proceedings 1105, (85 CH 2209-S, Ed. B. R. McAvoy, IEEE, New York, 1985).

21. "Relaxation Attenuation in $Er_{0.187}Ho_{0.813}Rh_4B_4$ and $HoRh_4B_4$," K. J. Sun, R. Sorbello, M. Levy, M. B. Maple and M. S. Torikachvilli, IEEE 1986 Ultrasonics Symposium Proceedings, 1123 (86 CH 2375-4, Ed. B. R. McAvoy, IEEE, New York 1986).

22. "Percolation Model for the Surface Acoustic Wave Attenuation in a Superconducting Lead Film," J. Schmidt and M. Levy, IEEE 1985 Ultrasonic Symposium Proceedings 1089, (85 CH 2209-S, Ed. B. R. McAvoy, IEEE, New York, 1985).

23. "Ultrasonic Attenuation and the Resistive Transition in a Superconducting Granular Lead Film," M. Levy, J. Schmidt, M. Revzen, A. Ron, and B. Shapiro, C. G. Kuper, Phys. Rev. B43, 1508 (1986).

24. "A Possible Technique for Determining the Average Grain Size in Thin Superconducting Granular Films," J. Schmidt and M. Levy, 1986 Applied Superconductivity Conference Proceedings, IEEE Transaction on Magnetics MAG-23, 1034 (1986).

25. "Attenuation of Surface Acoustic Waves in Superconducting In/InO_x Films," J. Schmidt, M. Levy and A. Hebard, IEEE 1986 Ultrasonics Symposium Proceedings, 1097 (CH 2375-4, Ed. B. R. McAvoy, IEEE, New York, 1986.

26. "Detection of Bound Vortex-Antivortex Pairs in a Superconducting Thin Film by Surface Acoustic Waves," A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler, Proceedings on Materials and Mechanisms of Superconductivity, (eds. K. A. Gschneider, Jr. and E. L. Wolf, North Holland Publishing Co. 1985) Physica 135B, 128 (1985).

27. "Detection of Bound Vortex-Antivortex Pairs in a Superconducting Thin Film by Surface Acoustic Waves," A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler, Journal de Physique 46, C10-703 (1985).

28. "Proximity Coupling of Surface Acoustic Waves to a Superconducting Al_xO_{1-x} Film," A. Schenstrom and M. Levy, 1986 Applied Superconductivity Proceedings IEEE Transaction on Magnetics MAG-23 1030 (1986).

29. "Attenuation of SAW Due to Electron Phonon Interaction," M. Levy and S. Schneider, Condensed Matter Physics: The Theodore D. Holstein Symposium (Ed. Raymond Orbach, Springer Verlag, New York, 1986) p.74.

30. "Poisson's Ratio Dependence of Electron Phonon SAW Attenuation," Susan C. Schneider and Moises Levy, IEEE 1987 Ultrasonics Symposium Proceedings, Denver, October 14-16 (1987) 1159 (87 CH 2492-7, Ed. B. R. McAvoy, IEEE, New York, 1987).

31. "Surface Acoustic Wave Investigation of Superconducting Films," M. Levy, Journal de Physique 46, C10-691 (1985).

32. "Top-Loading Dilution Refrigerator for High Frequency Measurements," H. P. Baum, Y. J. Qian, A. Schenstrom, M.-F. Xu, M. Levy and B. K. Sarma, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 1731.

CONFERENCES

Seven invited talks and 26 contributed papers were presented at conferences.

I. Invited Papers

1. "Surface Acoustic Wave Investigation of Superconducting Films," Eighth International Conference on Internal Friction and Ultrasonic Attenuation in Solids, University of Illinois at Urbana-Champaign, Illinois, June 3-6, 1985.

2. "Surface Acoustic Wave Investigation of Superconducting Granular Pb Films," Invited Poster, Gordon Research Conference on Superconducting Film, Plymouth, New Hampshire, August 26-30, 1985.

3. "Surface Acoustic Wave Investigation of Superconducting Films by Means of the Acoustoelectric Effect," 110th Meeting: Acoustical Society of America, Nashville, Tennessee, November 4-8, 1985.

4. "Surface Acoustic Wave Interaction with Thin Magnetic Films," 112th Meeting: Acoustical Society of America, Anaheim, California, December 8-12, 1986.

5. "Ultrasonic Attenuation in Heavy Fermions and Ternary Compounds," International Workshop on Novel Mechanisms of Superconductivity, Berkeley, California, June 22-26, 1987.

6. "Ultrasonic Measurements in High T_c Superconductors," IEEE 1987 Ultrasonics Symposium, Denver, Colorado, October 14-16, 1987.

7. "Ultrasonic Investigation of Novel Superconductors," Engineering Conference and Exposition, Milwaukee, WI, April 13-14, 1988.

II. Contributed Papers

1. "Magnetic Field Dependence of the Ultrasonic Attenuation and Resistance of a Superconducting Granular Lead Film," J. Schmidt, A. Schenstrom and M. Levy, contributed paper, Eighth International Conference on Internal Friction and Ultrasonic Attenuation in Solids, June 3-6, 1985, held in Urbana, Illinois.
2. "Detection of Bound Vortex-Antivortex Pairs in a Superconducting Thin Film by Surface Acoustic Waves," A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler, contributed paper, ibid.
3. "Surface Acoustic Wave Attenuation Below the Kosterlitz-Thouless Transition," A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler, Contributed Poster, Materials and Mechanisms of Superconductivity Conference, May 29-31, 1985, held in Ames, Iowa.
4. "Ultrasonic Attenuation Measurement of $Er_{1-x}Ho_xRh_4B_4$," K. J. Sun, M. Levy, M. B. Maple and M. S. Torikachvilli, Contributed Poster, ibid.
5. "Percolation Model for the Surface Acoustic Wave Attenuation in a Superconducting Granular Lead Film," J. Schmidt and M. Levy, contributed paper, ibid.
6. "Ultrasonic Attenuation Measurements in the Re-entrant Superconductors $Er_{0.187}Ho_{0.813}Rh_4B_4$ and $Er_{0.705}Ho_{0.295}Rh_4B_4$," K. J. Sun, M. Levy, M. B. Maple and M. S. Torikachvilli, contributed paper, ibid.
7. "A Possible Technique for Determining the Average Grain Size in Thin Superconducting Granular Films," J. Schmidt and M. Levy, contributed poster, 1986 Applied Superconductivity Conference, Baltimore, Maryland, Sept. 28-Oct. 3, 1986.

8. "Proximity Coupling of Surface Acoustic Waves to a Superconducting Al_xO_{1-x}Film," A. Schenstrom and M. Levy, contributed poster, ibid.

9. "Relaxation Attenuation in $Er_{0.187}Ho_{0.813}Rh_4B_4$ and $HoRh_4B_4$," K. J. Sun, R. Sorbello, M. Levy, M. B. Maple and M. S. Torikachvilli, IEEE 1986 Ultrasonics Symposium, contributed paper, Williamsberg, Virginia, Nov. 17-19, 1986.

10. "Attenuation of Surface Acoustic Waves in Superconducting In/InO_x Films, J. Schmidt, M. Levy and A. Hebard, contributed paper, ibid.

11. "Ultrasonic Relaxation Attenuation of $Er_{1-x}Ho_xRh_4B_4$," K. J. Sun, R. Sorbello, M. Levy, M. B. Maple, M. S. Torikachvilli, Bull Amer. Phys. Soc. 32, 561 (1987). APS March Meeting held in New York City, March 16-20, 1987. Contributed paper.

12. "Longitudinal Sound in URu_2Si_2," K. J. Sun, A. Schenstrom, B. K. Sarma, M. Levy, J. B. Ketterson, and D. Hinks, Ibid, p. 641. Contributed paper.

13. "Proximity coupling of a Surface Acoustic Waves to a 2-D Electron Gas," A. Schenstrom, M.-F. Xu, H.-P. Baum, B. K. Sarma, M. Levy, and Y. J. Qian, APS March Meeting held in New York City, March 16-20, 1987, Bull Amer. Phys. Soc. 32, No. 6, p. 1425 (1987). Contributed poster.

14. "Ultrasonic Attenuation Measurements in the Mixed State of UPt_3," Y. J. Qian, M.-F. Xu, A. Schenstrom, H. P. Baum, M. Levy, B. K. Sarma, J. B. Ketterson, and D. Hinks, Ibid, p. 1410. Contributed poster.

15. "Possible Phase Transition in UPt_3 in a Magnetic Field," M.-F. Xu, Y. J. Qian, A. Schenstrom, H.-P. Baum, J. B. Ketterson, D. Hinks, M. Levy and Bimal K. Sarma, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, August 1987. Contributed paper.

16. "Oscillations in Ultrasonic Attenuation: Real or Spurious?", Y. J. Qian, A. Schenstrom, M.-F. Xu, H.-P. Baum, Bimal K. Sarma, M. Levy and J. B. Ketterson, Ibid. Contributed paper.

17 "Top-Loading Dilution Refrigerator for High Frequency Measurements," H. P. Baum, Y. J. Qian, A. Schenstrom, M.-F. Xu, M. Levy and B. K. Sarma, Ibid. Contributed paper.

18. "Oscillations in the Attenuation of Surface Acoustic Waves Due to Proximity Coupling to a 2D Electron Gas," A. Schenstrom, M.-F. Xu, H.-P. Baum, B. K. Sarma, M. Levy and Y. J. Qian, Ibid. Contributed paper.

19. "Field Dependent Behavior of Longitudinal Ultrasonic Attenuation in UPt_3, M.-F. Xu, A. Schenstrom," H.-P. Baum, Y. J. Qian, J. B. Ketterson, D. J. Hinks, M. Levy and B. K. Sarma, Proceedings of Conference on Magnetism and Magnetic Materials, Chicago, Nov. 9-12, (1987). Contributed poster.

20. "Shift in Maximum of Sound Attenuation with Magnetic Field in UPt_3," H.-P. Baum, M.-F. Xu, Y. J. Qian, A. Schenstrom, J. B. Ketterson, D. H. Hinks, M. Levy and B. K. Sarma, Ibid, Contributed poster.

21. "Poisson's Ratio Dependence of Electron Phonon SAW Attenuation," Susan C. Schneider and Moises Levy, IEEE 1987 Ultrasonics Symposium, Denver, October 14-16, 1987. Contributed paper.

22. "Hysteresis in Ultrasonic Attenuation in Superconducting UPt_3," B. K. Sarma, A. Schenstrom, M.-F. Xu, H.-P. Baum, Y. J. Qian, M. Levy, J. B. Ketterson, D. W. Hess, J. A. Sauls and D. Hinks, 1988 March APS Meeting (New Orleans).

23. "Elastic Constants of Sinter-forged $YBa_2Cu_3O_{7-\delta}$," Shireen Adenwalla, Z. Zhao, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeier, J. B. Ketterson, M.-F. Xu, M. Levy and B. K. Sarma, 1988 March APS Meeting (New Orleans).

24. "Ultrasonic Attenuation Measurements in Sinter-forged $YBa_2Cu_3O_{7-\delta}$," M.-F. Xu, M. Levy, B. K. Sarma, Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Peoppelmeier and J. B. Ketterson, 1988 March APS Meeting (New Orleans).

25. "Measurements of $J_{xx}(\omega,k)$ in the Quantum Hall Regime Using Surface Acoustic Waves," A. Schenstrom, M. Levy, B. K. Sarma and H. Morkoc, 1988 March APS Meeting (New Orleans).

26. "Frequency Dependent Ultrasonic Attenuation Behavior of $YBa_2Cu_3O_7$," K. J. Sun, W. P. Wingfried, M.-F. Xu, M. Levy, B. K. Sarma, and R. Badon, 1988 March APS Meeting (New Orleans).

TECHNICAL PERSONNEL

In addition to the principal investigator the following faculty, post docs and graduate students have worked on this grant. Three graduate student received a Ph.D. during this period.

Faculty

Associate Professor Bimal Sarma	SAW measurements on superconducting films and two dimensional electron gas. Bulk wave measurements on sinter forged and sintered samples of $YBa_2Cu_3O_7$, and heavy Fermion superconductors

Post Docs

Dr. Anders Schenstrom	SAW measurements on superconducting films, Quantum Hall Effect and heavy Fermion superconductors.

Y. J. Qian	Installation, testing and modification of dilution refrigerator. Measurements on heavy Fermion superconductors and Quantum Hall Effect.

Graduate Research Assistants

Full Time:

Mr. Hughes Pierre Baum	SAW measurements on superconducting films.
Mr. Anders Schenstrom	SAW measurements of two dimensional electron gas.
Mr. Jeff Schmidt	SAW investigation of superconducting granular Pb films and amorphous In/InO_x films.
Mr. Keun-Jenn Sun	Ultrasonic investigation of ternary ferromagnetic superconductors and pure vanadium single crystals.
Mr. Min Feng Xu	Bulk wave measurements of sinter forged and sintered $YBa_2Cu_3O_7$, and an heavy Fermion superconductors.

Part Time

Mr. David Bein	Preparation of high T_c superconducting sintered samples
Ms. Jin Zheng	SAW measurements of high T_c superconductors.

Ph.D.'s

Mr. Keun-Jenn Sun submitted his Ph.D. thesis entitled "Ultrasonic Investigation of Re-entrant Superconductor and Ferromagnetic Compounds of the $Er_{1-x}Ho_xRh_4B_4$ System" under the supervision of M. Levy. He received his Ph.D. in August 1986.

Mr. Jeffrey Schmidt submitted his Ph.D. thesis entitled "Surface Acoustic Wave Investigation of Amorphous and Granular Superconducting Films," under the supervision of M. Levy. He received his Ph.D. in August 1987.

Mr. Anders Schenstrom submitted his Ph.D. thesis entitled "Proximity Coupling of Surface Acoustic Waves to Quasi 2-Dimensional Systems" under the supervision of M. Levy. He received his Ph.D. in December, 1987.